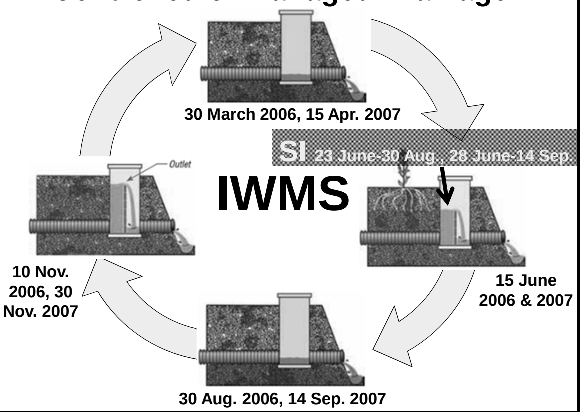
Controlled or Managed Drainage:



Corn Response to an Integrated Water Management System

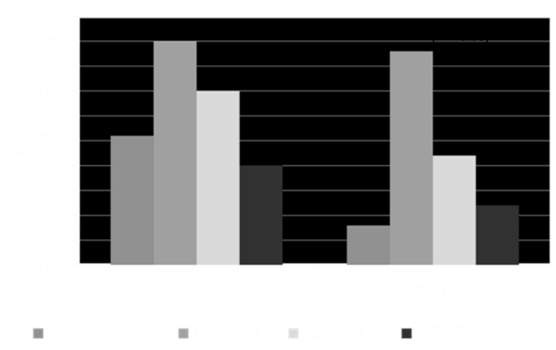
	Yield increase			
Year(s) and Environment	DO 20’	DSI 20’	DO 20’	DSI 20’
	---Bu/acre---		--------%--------	
06: Dry-Moderate	8	72	6	55
02,05,12,14: Wet-Dry	14	70	22	108
03,07: Wet-Moderate	26	56	25	48
04,08,09,10,11: Wet-Wet	35	31	25	22
Average	20	57	20	58

2004-2005: PCU, Irrigation, Drainage on NU and Yield. *Nelson et al., 2009. Agron. J.*

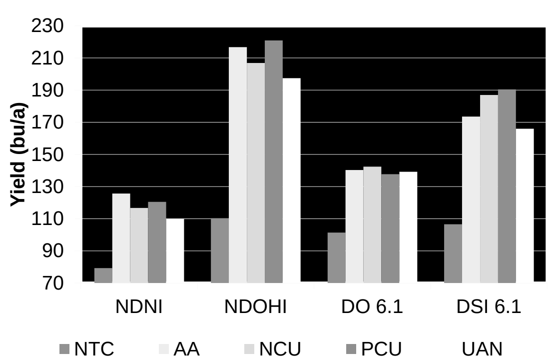
2006-2007: N Source & Drainage on Yield *Nelson and Motavalli, 2014. App. Eng. in Agric.*

2008-2010: Drainage and High Yield Hybrids *Nelson et al., 2012. Intl. J. Agron.*

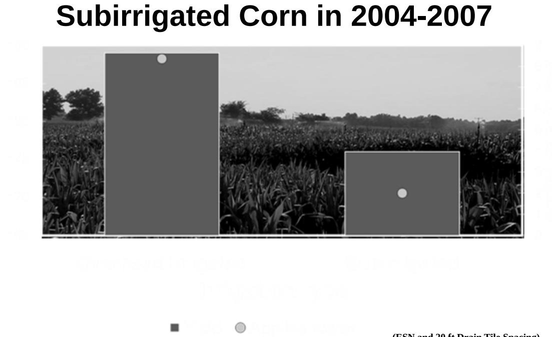
High Yielding Corn Hybrids and IWMS (2008 and 2010, Wet-Wet)



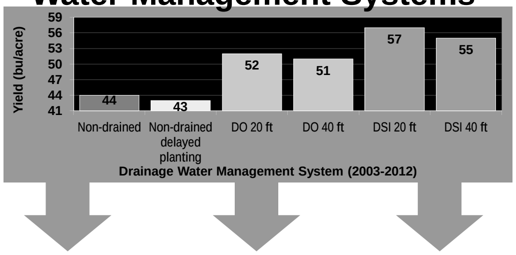
N Source and Water Management Systems (2006 & 2007)



Grain Yield (2004-2009) and Applied Water for Overhead Irrigated and Subirrigated Corn in 2004-2007



Soybean Response to Integrated Water Management Systems



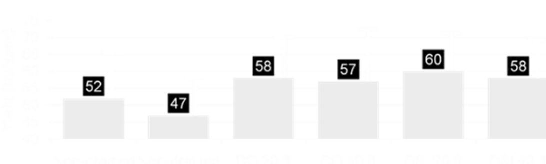
2003-2006: Yield Response to DWM.
Nelson et al., 2011. Agron. J.

2007 & 2008: High Yield Cultivars and DWM.
Nelson et al., 2012. Crop Management.

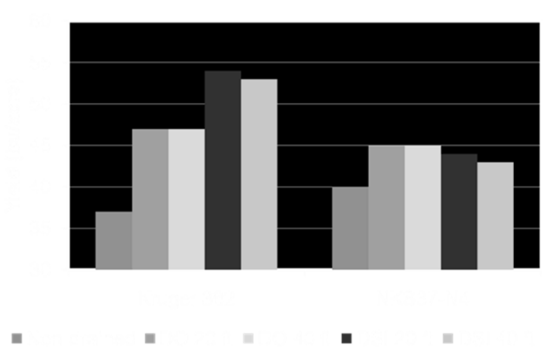
2009 & 2010: IWMS & Fungicide Management.
Nelson et al., 2011. Agron. J.

Soybean Yield Response (2003-2006)

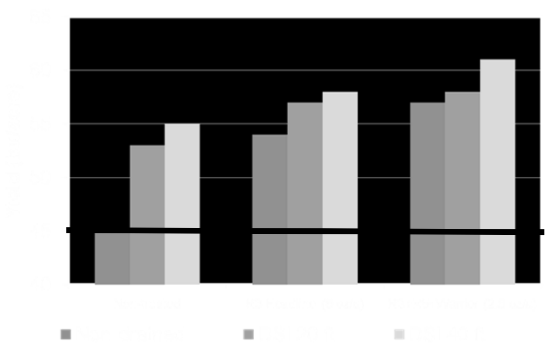
Drain tile spacing	2003 (wet-mod.)		2004 (wet-wet)		2005 (dry-dry)		2006 (mod.-mod.)
	DO	DSI	DO	DSI	DO	DSI	
	---------------------------- Bu/acre ----------------------------						
Non-drained	40	42*	57	45*	38	38*	62
20 ft spacing	*48*	*47*	*71*	*72*	*46*	**58**	*65*
40 ft spacing	*48*	*47*	*72*	*69*	41	**51**	*66*
LSD (*P* = 0.05)	----- 4 -----		----- 9 -----		----- 8 -----		----- 2 -----



High Yielding Soybean Cultivars and IWMS (2007-2008)



IWMS and Fungicide Management (2009-2010)



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660-739-4410

Nelsonke@missouri.edu

MU DRAINAGE AND SUBIRRIGATION (MUDS) RESEARCH UPDATE FOR CLAYPAN SOILS

Kelly A. Nelson and Chris Dudenhoeffer

Background:

Economic situations have caused several Missouri farmers to re-evaluate production systems that maximize yield and maintain environmental sustainability. Agricultural drainage is not a new concept; however, utilizing drainage as part of an integrated water management system (IWMS) is a relatively new concept that has been shown to improve water quality and sustain agricultural viability (Frankenberger et al., 2006). Subsurface drainage water from agricultural lands contributes to the quantity and quality of water in receiving streams when properly implemented water management systems are adopted.

Upland, flat claypan soils commonly have a seasonal perched water table from November to May, which is caused by an impermeable underlying clay layer that restricts internal drainage. Research in other states has reported increased crop production using IWMS's that incorporate subsurface drainage and subirrigation. The MUDS research program was initiated to determine the suitability of claypan soils for drainage and a drainage/subirrigation (DSI) water-table management system, and to evaluate the effect of the systems on corn and soybean grain yield at different drain tile spacings compared to non-drained claypan soil.

Methods:

Subsurface drainage and DSI water-table management systems were installed in July, 2001. This research was arranged as a split-plot design with two main plots (drainage and drainage/subirrigation systems) and a factorial arrangement of sub-plots including a non-drained control and three drain tile spacings (20, 30, and 40 ft) and two crops (corn and soybean) with four replications. The corn and soybean main plot size was 60 to 80 by 150 ft depending on the drain tile spacing. Soil was a Putnam silt loam with 10%, 75%, and 15% sand, silt, and clay, respectively. Field management information and rainfall data are summarized in Tables 1 and 2, respectively. A delayed planting control was included in the design. Non-drained checks usually delay planting of drained treatments in research projects; therefore, two non-drained controls were included in the design to reduce the confounding effect of planting date on results. One is planted at the time the drained treatments are planted regardless of the soil conditions. The other is delayed based on typical soil conditions that are suitable for planting.

The DSI system was shifted into controlled drainage mode in June, 2002 and a temporary water supply system was implemented for subirrigation during the growing season. The water supply did not provide enough volume to substantially raise the water table; however, baseline data were established on the impact of subirrigation on production in 2002. These results have been similar to subsequent years and were included in the results. Soybean plots equipped with a water-table management system were not subirrigated in 2002. Subirrigation of soybean was initiated in 2003 and corn was subirrigated from 2004 to the present. Table 1 summarizes the subirrigation timing schedule while Table 2 summarizes the amount of water supplied through the subirrigation system on the 20 ft lateral spacing from 2004 to 2007. Water meters recorded the quantity of water supplied through the subirrigation system. This was converted to inch equivalents of rainfall.

Additional sub-plots were added to evaluate soybean cultivars, corn hybrids and N management systems which are outlined below in the results section. Research was initiated in

2004 and 2005 to evaluate the use of slow-release nitrogen fertilizer (ESN, Agrium, Alberta, Canada) applied to corn to control nitrogen loss when there were differences in soil moisture conditions and drainage (Nelson et al., 2009). Since there was no delay in early planted corn in 2002 and 2003, an overhead irrigation system was installed to replace this treatment. Corn was irrigated according to the Woodruff irrigation scheduling chart. The amount of water applied with the overhead irrigation system was reported in Table 2. Sub-plots included coated (ESN) and non-coated urea at 0, 125, and 250 lb N/a. Crop performance has been evaluated above and between drain tiles over the experiment; however, data was not presented in this report.

Additional sub-plots were incorporated into the design to evaluate how management factors affected crop response to water management systems. Corn research in 2006 and 2007 compared the relative corn growth response and environmental N losses after application of different N fertilizer sources under a range of soil moisture conditions imposed by drainage and irrigation, and examined the spatial differences in soil N transformations and N losses during the growing season between drainage and subirrigation tile lines (Nelson et al., 2009). Preplant injected anhydrous ammonia, urea ammonium nitrate, urea, or polymer coated urea applied at 150 lbs N/acre were incorporated following application (Nelson and Motavalli, 2013). The number of soybean cultivars evaluated was expanded to five in 2007 and 2008 (Nelson et al. 2012); corn hybrid response was the primary focus in 2008, 2009, and 2010 (Nelson and Smoot, 2012); and soybean fungicide management treatments were included in 2009 and 2010 (Nelson and Meinhardt, 2011).

Results:

Soybean Response to Drainage and Subirrigation (2003, 2004, 2005, and 2006). Since shallow drain tile depths and narrow spacings are recommended for claypan soils, field research from 2003–2006 was conducted to evaluate the effects of drainage (DO) and DSI on planting date and the effects of DO and DSI at 20 and 40 ft spacings on soybean yield compared to non-drained (ND) and non-drained delayed planting (NDDP) controls on claypan soils. A summary of this research follows in a subsequent section, and additional details are available in:

Nelson, K.A., R.L. Smoot, and C.G. Meinhardt. 2011. Soybean response to drainage and subirrigation on a claypan soil in Northeast Missouri. Agron. J. 103:1216-1222.

High Yield Soybean Cultivars (2007 and 2008). High yielding soybean cultivars were included in the experimental design in 2007 and 2008. A summary of this research follows in a subsequent section, and additional details are available in:

Nelson, K.A., C.G. Meinhardt, and R.L. Smoot. 2012. Soybean cultivar response to subsurface drainage and subirrigation in Northeast Missouri. Online. Crop Management. doi:10.1094/CM-2012-0320-03-RS.

Soybean Fungicide Treatments (2009 and 2010). Fungicide treatments were included in the soybean experimental design in 2009 and 2010. These included a non-treated control, Headline at R3, Headline at R5 soybean, Headline at R3 and R5, and Headline plus Warrior at R3 and R5. A summary of this research follows in a subsequent section, and additional details are available in:

Nelson, K.A., and C.G. Meinhardt. 2011. Soybean yield response to pyraclostrobin and drainage water management. Agron. J. 103:1359-1365.

Polymer-coated Urea, Irrigation, and Drainage Affect Nitrogen Utilization and Yield (2004 and 2005). Slow-release N fertilizers, such as polymer-coated urea (PCU), may increase crop N use and reduce NO_3-N leaching. Research was conducted to evaluate NO_3-N concentrations of soil water samples in noncoated urea (NCU) and PCU treated plots under different water management systems, and to determine differences in crop yields and N utilization among water and urea management systems. Additional details are available in:

Nelson, K.A., S.M. Paniagua, and P.P. Motavalli. 2009. Effect of polymer coated urea, irrigation, and drainage on nitrogen utilization and yield of corn in a claypan soil. Agron. J. 101:681-687.

Nitrogen Source and Drain Tile Spacing Effects on Corn Yield (2006 and 2007). Field research evaluated the effects of nitrogen (N) sources [non-treated control, anhydrous ammonia, urea, polymer-coated urea (PCU), and 32% urea ammonium nitrate (UAN) at 150 lbs N acre^{-1}] and water management systems [drained, non-irrigated (DNI) at 20, 30, and 40 ft spacings; non-drained, non-irrigated (NDNI); non-drained, overhead irrigated (NDOHI); and drained plus subirrigated (DSI) at 20, 30, and 40 ft spacings] on yield, plant population, grain protein, and grain N removal. A summary of this research follows. Additional details are available in:

Nelson, K.A., and P.P. Motavalli. 2013. Nitrogen source and drain tile spacing affects corn yield response in a claypan soil. Applied Engineering in Agriculture. 29:*In press*. doi: 10.13031/aea.29.9809.

High Yield Corn Hybrids (2008, 2009, and 2010). Additional corn hybrids were evaluated to include Kruger 2114, LG 2642, Asgrow 785, DeKalb C61-73, and DeKalb C63-42 during a period of extremely high rainfall. A summary of this research follows in a subsequent section, and additional details are available in:

Nelson, K.A., and R.L. Smoot. 2012. Corn hybrid response to water management practices on claypan soil. Int. J. Agron. doi:10.1155/2012/925408.

Summary of Long-term MUDS Research (2002 to 2013):

- Soybean planting date was delayed an average of 2 days for the non-drained control compared to drained soils from 2002 to 2013 (Table 1).
- Drainage only increased average corn grain yields up to 24 bu/acre while DSI has increased average yields up to 52 bu/acre when compared with non-drained, non-irrigated soil planted on the same day from 2004 to 2013 (Table 3).
- Overhead irrigation increased grain yield 5% compared to DSI corn with 20 ft laterals from 2004 to 2010 (Table 3). However, applied water was on average 4 times greater for overhead irrigated corn compared with DSI corn on a 20 ft drain tile spacing from 2004 to 2007 (Table 2).
- Soybean grain yield with DO has averaged up to 9 bu/acre more than the non-drained delayed planting control (Table 4). Similarly, DSI had soybean grain yields up to 14 bu/acre greater than the non-drained delayed planting controls.

Acknowledgments:

The authors would like to thank the Missouri Soybean Merchandising Council; Missouri Corn Growers Association; Landmark Irrigation, Inc., Taylor, MO; Agri Drain Corp., Adair, IA; Hawkeye Tile Inc., Taylor, MO; Liebrecht Manufacturing, Continental, OH; Timewell Tile, Timewell, IL; IMI Equipment, Kahoka, MO; BASF; Syngenta; Monsanto; Pioneer Hi-Bred; and Kruger Seeds for their support. In addition, a special thanks is extended to Randall Smoot, Matthew Jones, Dana Harder, Keith Lay, Chris Bliefert, Clinton Meinhardt, and Ben Bradley for their technical assistance.

Available at: http://aes.missouri.edu/greenley/research/muds.stm

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Frankenberger, J., E. Kladivko, G. Sands, D. Jaynes, N. Fausey, M. Helmers, R. Cooke, J. Strock, K. Nelson, and L. Brown. 2006. Drainage water management for the Midwest: Questions and answers about drainage water management for the Midwest. Purdue Ext., p. 8.

Nelson, K.A., and C.G. Meinhardt. 2011. Soybean yield response to pyraclostrobin and drainage water management. Agron. J. 103:1359-1365.

Nelson, K.A., C.G. Meinhardt, and R.L. Smoot. 2012. Soybean cultivar response to subsurface drainage and subirrigation in Northeast Missouri. Online. Crop Management. doi:10.1094/CM-2012-0320-03-RS.

Nelson, K.A., S.M. Paniagua, and P.P. Motavalli. 2009. Effect of polymer coated urea, irrigation, and drainage on nitrogen utilization and yield of corn in a claypan soil. Agron. J. 101:681-687.

Nelson, K.A., and R.L. Smoot. 2012. Corn hybrid response to water management practices on claypan soil. Int. J. Agron. doi:10.1155/2012/925408.

Nelson, K.A., R.L. Smoot, and C.G. Meinhardt. 2011. Soybean response to drainage and subirrigation on a claypan soil in Northeast Missouri. Agron. J. 103:1216-1222.

Table 1a. Field information and selected management practices for corn and soybean in the first decade of this research (2002-2011).

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Corn										
Tillage	Nov. 12, 2001 chisel plowed; Apr. 5, 2002 field cultivated	No-till	Nov. 17, 2003 chisel plowed; Mar. 24, 2004 and Apr. 15, 2004 field cultivated	Mar. 13, 2005 disk-harrowed; Apr. 8, 2005 field cultivated	Nov. 10, 2005 chisel plowed; Mar. 2, 2006 disk-harrowed and Apr. 11, 2006 field cultivated	Nov. 22, 2006 chisel plowed, May 1 and May 2, 2007 field cultivated	May 2, 2008 Tilloll	Nov. 25, 2008 chisel plowed; April 23, 2009 Tilloll	May 19-20, 2010 Tilloll 2x	April 13Tilloll
Row spacing (in.)	30	30	30	30	30	30	30	30	30	30
Planting date	Apr. 17	Apr. 12	Apr. 15	Apr. 8	Apr. 11	May 13	May 5	April 24	May 28	Apr. 14,
Delayed planting date	None	None	None	None	None	May 18	None	May 12	None	June 1
Hybrid(s)	Pioneer 33P67	Pioneer 33P67	Pioneer 33P67	Pioneer 33P67	DeKalb C61-68	DeKalb C61-68	Kruger 2114, LG 2642, Asgrow 785, DeKalb C61-73, DeKalb C63-42	Kruger 2114, LG 2642, Asgrow 785, DeKalb C61-73, DeKalb C63-42	Kruger 2114, LG 2642, Asgrow 785, DeKalb C61-73, DeKalb C63-42	DK63-42
Seeding rate (seeds/a)	30,000	31,000	32,000	34,000	33,000	33,000	32,000	33,000	33,000	30,800
Controlled drainage date(s)	June 15	June 10	July 1	June 1	June 15	June 15	July 17	June 25	July 6, Oct. 29	July 5
Subirrigation date	July 19-Aug. 30[a]	——[b]	July 20-Aug. 25	June 1-Sep. 6	June 23-Aug. 30	June 28-Sep. 14	July 17-Sept. 10	June 25-Sep. 16	Aug. 2-Sept. 10	July 5-Sep. 27
Drainage mode	Sep. 1	Sep. 15	Sep. 25	Sep. 6	Aug. 30	Sep. 14	July 25-Aug.4, Sep. 10	Sep. 16	Sept. 10-Oct. 29	Apr. 15
Harvest date	Sep. 15	Sep. 30	Nov. 12	Sep. 20	Sep. 8	Oct. 6	Nov. 4	Nov. 28	Oct. 15	Sep. 23
Fertility	Fall, 2001 17-80-100 Apr. 17, 2002 200-0-0 Ammonium nitrate	Fall, 2002 17-80-100 Apr. 3, 2003 250-0-0 Anhydrous ammonia	Mar. 24, 2004 17-80-140-3 + 5 lb/a Zn Apr. 15, 2004 125-0-0 urea or ESN 250-0-0 urea or ESN	Mar. 17, 2005 12-60-120 Apr. 8, 2005 125-0-0 urea or ESN 250-0-0 urea or ESN	Apr. 11, 2006 150-0-0 urea, ESN, urea ammonium nitrate, or anhydrous ammonia	May 1, 2007 22-104-300 150-0-0 urea, ESN, urea ammonium nitrate, or anhydrous ammonia	May 1, 2008 180-0-0 anhydrous ammonia, Nov. 26, 2008 30-80-160	Apr. 8, 2009 180-0-0 anhydrous ammonia	May 27, 2010 180-0-0 anhydrous ammonia	Apr. 12 180-0-0 anhydrous ammonia
Timing, date	PRE, Apr. 19	PRE, Apr. 12	Early POST, Apr. 27	Early POST, May 6	Early POST, May 15	Early POST, May 19	Early POST, May 29	Early POST, May 21	PRE, May 31	Burndown, Apr. 3
Herbicide	Bicep II Magnum + Princep + 2,4-D ester	Guardsman MAX + Princep + Touchdown + Quest	Lumax	Lumax + NIS	Lumax + NIS	Roundup WeatherMAX + AMS	Roundup PowerMAX + Lumax + AMS	Guardsman MAX + Roundup PowerMAX	Sharpen + Roundup PowerMAX	Roundup PowerMAX + Verdict + AMS + NIS
Rates	2.6 qt/a + 1 qt/a + ½ pt/a	2 qt/a + 1 qt/a + 1 pt/a + ½ pt/a	3 qt/a	3 qt/a + 0.25% v/v	3 qt/a + 0.25% v/v	22 oz/a + 17 lb/100 gal	22 oz/a + 3 qt/a + 17 lb/100 gal	4 pt/a + 22 oz/a	1 oz/a + 22 oz/a	30 oz/a + 5 oz/a + 17 lb/100 gal + 0.25 % v/v
Timing, date		POST, June 5				POST, June 11		POST, June 25	Early POST, June 22	Early POST May 17

Herbicide		Callisto + atrazine + COC + AMS				Bicep II Magnum + Roundup OriginalMAX + AMS		Roundup PowerMAX + Quest	Keystone	Degree Xtra
Rates		3 oz/a + 8 oz + 1% v/v + 2 lb/a				2.5 qt/a + 22 oz/a + 17 lb/100 gal		32 oz/a + 1 pt/100 gal	3.4 qt/a	3 qt/a
Timing, date									POST, June 29	POST, July 1
Herbicide									Roundup PowerMAX + AMS	Roundup WeatherMAX + UAN
Rates									30 oz/a + 17 lb/100 gal	32 oz/a + 1 qt/a
Insect management	Kernel guard	Gaucho seed treatment	Poncho 250 seed treatment	Poncho 250 seed treatment; Warrior 3.8 oz/a, May 6	Poncho 250 seed treatment; Warrior 3.8 oz/a, May 15	Poncho 250 seed treatment, Warrior 2.2 oz/a, May 11; Perm up 6 oz/a;	Poncho 250 seed treatment	Poncho 250 seed treatment	Poncho 250 seed treatment	Poncho 250 seed treatment; Warrior II 2 oz/a, May 17
Disease management						Headline 6 oz/a, July 17				Headline 6 oz/a, July 21
pHs	6.5 ± 0.5	6.8 ± 0.3	6.7 ± 0.1	6.9 ± 0.2	6.6 ± 0.1	6.9 ± 0.1	6.6 ± 0.05	6.9 ± 0.2	6.7 ± 0.3	6.7 ± 0.3
SOM (%)	2.6 ± 0.2	1.9 ± 0.1	2.1 ± 0.1	2.1 ± 0.1	1.8 ± 0.1	1.9 ± 0.1	1.8 ± 0.08	2.1 ± 0.1	2.2 ± 0.4	2.0 ± 0.2
Soybean										
Tillage	November 12, 2001 chisel plowed Apr. 5, 2002 field cultivated	No-till	No-till	No-till	No-till	No-till	No-till	No-till	May 19-20, 2010 Tilloll 2x	No-till
Row spacing (in.)	7.5	7.5	7.5	7.5	7.5	15	15	7.5	15	15
Planting date	May 30	May 27	May 21	May 2	May 11	May 23	June 16	May 12	May 27	May 11
Delayed planting date	June 2	May 29	June 4	May 2	May 15	May 23	June 16	May 12	May 27	May 11
Cultivar	Pioneer 93B85	Kruger 401RR/SCN	Kruger 380RR/SCN	Kruger 380RR/SCN	Kruger 380RR/SCN	Asgrow 3602, Kruger 382, Pioneer 93M96, NK S37-N4, Morsoy3636	Asgrow 3602, Kruger 382, Pioneer 93M96, NK S37-N4, Morsoy3636	Asgrow 3803	Asgrow 3803	Asgrow 3803
Seeding rate (seeds/a)	180,000	200,000	200,000	200,000	200,000	200,000	200,000	200,000	200,000	180,000
Controlled drainage date(s)	June 20	June 25	July 1	June 1	June 15	June 15	July 17	June 25	July 6, Oct. 29	July 5
Subirrigation date	——[b]	Aug. 21	July 20-Aug. 25	June 1-Sep. 6	June 23-Sep. 30	June 28-Oct. 1	July17-Sep. 15	June 25-Sep. 16	Aug. 2-Sept. 10	July 5-Sep. 27
Drainage mode	Oct. 4	Sep. 15	Sep. 25	Sep. 15	Sep. 19	Oct. 1	July 25-Aug. 4, Sep. 15	Sep. 16	Sept. 10-Oct. 29	Apr. 15
Harvest date	Oct. 9	Oct. 8	Oct. 17	Oct. 10	Oct. 3	Oct. 30	Oct. 30			
Fertility	Fall, 2001 17-80-100	Fall, 2002 17-80-100	Mar. 24, 2004 17-80-140-3 & 5 lb/a Zn	Mar. 17, 2005 12-60-120	NA	May 1, 2007 22-104-300	Nov. 26, 2008 30-80-160	NA	NA	
Weed management										

Timing, date	Burndown, June 7	Burndown, June 20	Burndown, May 3	Early POST, June 1	Burndown, May 15	Burndown, May 18	Burndown, May 28	Burndown, May 21	PRE, May 31	Burndown, Apr. 3
Herbicide	Roundup UltraMAX + AMS	Roundup WeatherMAX + AMS	Roundup WeatherMAX + AMS	Roundup WeatherMAX + AMS	Roundup WeatherMAX + AMS	Roundup WeatherMAX + AMS	Roundup PowerMAX + Dual II Magnum	Roundup PowerMAX	Sharpen + Roundup PowerMAX	Roundup PowerMAX + Verdict + AMS + NIS
Rates	26 oz/a + 17 lb/100 gal	22 oz/a + 17 lb/100 gal	22 oz/a + 17 lb/100 gal	22 oz/a + 17 lb/100 gal	22 oz/a + 17 lb/100 gal	22 oz/a + 17 lb/100gal	32 oz/a + 1.66 pt/a	22 oz/a	1 oz/a + 22 oz/a	30 oz/a + 5 oz/a + 17 lb/100 gal + 0.25 % v/v
Timing, date	Postemergence, July 5	Postemergence, July 9	Postemergence, July 26	Postemergnce, July 11	POST, June 27	EPOST, June 11 LPOST, July 17	POST, July 17 LPOST, Aug. 26	POST, June 25	POST, June 29	POST, July 1
Herbicide	Roundup UltraMAX + AMS	Roundup WeatherMAX + AMS + DriftGuard	Roundup WeatherMAX + AMS + DriftGuard + Headline	Roundup WeatherMAX + AMS + DriftGuard + Quadris	Roundup WeatherMAX + AMS	Roundup OriginalMAX	POST: Roundup PowerMAX + AMS + FirstRate + NIS, LPOST: Roundup PowerMAX	Roundup PowerMAX + FirstRate + NIS + 32% N	Roundup PowerMAX + AMS	Roundup WeatherMAX + UAN
Rates	26 oz/a + 17 lb/100 gal	22 oz/a + 17 lb/100 gal + 2 oz/100 gal	22 oz/a + 17 lb/100 gal + 2 oz/100 gal + 6 oz/a	22 oz/a + 17 lb/100 gal + 2 oz/100 gal + 6 oz/a	22 oz/a + 17 lb/100 gal	22 oz/a + 17 lb/100 gal AMS	32 oz/a + 17 lb/100 gal + 0.3 oz/a, 22 oz/a	32 oz/a + 1/3 oz/a + 0.25% v/v + 1 qt/a	30 oz/a + 17 lb/100 gal	32 oz/a + 1 qt/a
Timing, date									POST, July 30	POST, July 5
Herbicide									Roundup PowerMAX + UAN + NIS	Reflex + COC + UAN
Rates									32 oz/a + 1 qt/a + 0.25% v/v	1.25 pt/a + 1 qt/a + 1 qt/a
Insect management	None	None	None	Warrior at 2.5 oz/a, July 11 Lorsban at 1 pt/a, Aug. 9	Warrior at 2.6 oz/a, June 27	Warrior at 2.2 oz/a, June 11; Permup 6 oz/a, July 17	Warrior at 2 oz/a, Aug., 26	R3, R5, or R3+R5	R3, R5, or R3+R5	None
Disease management	None	None	None	None	Headline 6 oz/a, June 27	Headline 7 oz/a, July 17	Quadris 6 oz/a, Aug. 26	R3, R5, or R3+R5	R3, R5, or R3+R5	Headline 6 oz/a, July 21
pHs	6.5 ± 0.5	6.7 ± 0.2	6.7 ± 0.2	6.8 ± 0.1	6.5 ± 0.1	7.0 ± 0.1	6.5 ± 0.1	6.7 ± 0.05	6.8 ± 0.2	7.0 ± 0.3
SOM (%)	2.6 ± 0.2	2.0 ± 0.1	2.2 ± 0.2	2.7 ± 0.2	2.0 ± 0.1	1.8 ± 0.1	2.0 ± 0.1	2.1 ± 0.2	2.0 ± 0.2	1.7 ± 0.1

[a]The water supply provided approximately 1500 gallon/replication/day. This did not provide enough volume to substantially raise the water table; however, preliminary data was established on the impact of subirrigation on corn production in 2002.
[b]Treatments were not included.

Table 1b. Field information and selected management practices for corn and soybean from 2012 to present.

	2012	2013
Corn		
Tillage	No-till, field cultivated reps 1&2	No-till
Row spacing (in.)	30	30
Planting date	Mar. 16 reps 3&4	May 16
Delayed planting date	Apr. 26 reps 1&2	
Hybrid(s)	DK63-42 reps 3&4, DK62-97 reps 1&2	GH H-8961 3111
Seeding rate (seeds/a)	33,000	33,000
Controlled drainage date(s)	May 3	June 26, Nov. 18
Subirrigation date	June 28-Aug. 27	June 26-Sep. 20
Drainage mode	Mar.10 corn, Apr 11 soybean	Mar. 13
Harvest date	Aug. 27	Oct. 8
Fertility	Nov. 15, 2011 180-0-0 anhydrous ammonia; Mar. 28, 2012 70-180-220	Nov. 28, 2012 16-80-120; Nov. 30 2012 180-0-0 anhydrous ammonia
Timing, date	Burndown, Mar. 19	Burndown, May 17
Herbicide	Verdict + Roundup PowerMAX + AMS + NIS	Sharpen + Roundup PowerMAx + MSO + UAN
Rates	5 oz/a + 22 oz/a + 17 lb/100 gal + 0.25 % v/v	1 oz/a + 32 oz/a + 1% v/v + 1 qt/a
Timing, date	Early POST, May 10	Early POST, June 4
Herbicide	Lexar + Roundup PowerMAX + NIS	Liberty + AMS
Rates	2.25 qt/a + 32 oz/a + 0.25% v/v	32 oz/a + 17 lb/100gal
Timing, date	POST, June 21	Early POST, June 5
Herbicide	Roundup PowerMAX + AMS + NIS	Lexar + NIS + AMS
Rates	30 oz/a + 17 lb/100 gal + 0.25% v/v	3 qt/a + 0.25% v/v + 17 lb/100 gal
Insect management	Poncho 250 seed treatment; Warrior II 2 oz/a, May 10; Lorsban 1 pt/a, July 10	None
Disease management	Headline 6 oz/a, July 10	None
pHs	7.0 ± 0.3	
SOM (%)	1.7 ± 0.1	
Soybean		
Tillage	No-til	No-till
Row spacing (in.)	15	7.5
Planting date	Apr. 26	May 17
Delayed planting date	Apr. 26	May 17
Cultivar	Asgrow 3730	MorSoy LL3759N
Seeding rate (seeds/a)	180,000	160,000
Controlled drainage date(s)	May 3	June 26, Nov. 18
Subirrigation date	June 28-Aug. 27	June 26-Sep. 20
Drainage mode	Apr 11, Sep. 4	Mar. 13
Harvest date		Oct. 11
Fertility		Nov. 28, 2012 16-80-120
Weed management		
Timing, date	Burndown, Mar. 19	Burndown, May 17
Herbicide	Verdict + Roundup PowerMAX + AMS + NIS	Sharpen + Roundup PowerMAx + MSO + UAN
Rates	5 oz/a + 22 oz/a + 17 lb/100 gal + 0.25 % v/v	1 oz/a + 32 oz/a + 1% v/v + 1 qt/a
Timing, date	POST, May 11	Early POST, June 4
Herbicide	Reflex + Roundup PowerMAX + AMS + NIS	Liberty + AMS
Rates	1.25 pt/a + 30 oz/a + 17 lb/100 gal + 0.25% v/v	32 oz/a + 17 lb/100gal
Timing, date	POST, June 21	POST, June 28
Herbicide	Roundup PowerMAX + AMS + NIS	Liberty + AMS + Prefix + NIS
Rates	30 oz/a + 17 lb/100 gal + 0.25% v/v	32 oz/a + 17 lb/100gal + 2.25 pt/a + 0.25%v/v
Insect management	Warrior II 2 oz/a, May 11; Lorsban 1 pt/a, July 10	None
Disease management	Headline 6 oz/a, July 10	None
pHs	6.7 ± 0.3	
SOM (%)	2.0 ± 0.2	

Table 2. MUDS annual rainfall, overhead irrigation, and subirrigation totals for 2002 to 2013.

	2002	2003	2004			2005			2006			2007			2008		2009		2010	2011	2012	2013
Time period	Precip.[a]	Precip.	Precip.	OhIrr.	SubIrr.[b]	Precip.	OhIrr.	SubIrr.	Precip.	OhIrr.	SubIrr.	Precip.	OhIrr.	SubIrr.	Precip.	OhIrr.	Precip.	OhIrr.	Precip.	Precip.	Precip.	Precip.
	Inches																					
January	0.65	0.29	1.14	0	0	2.74	0	0	2.11	0	0	0.83	0	0	0.78		0.01		1.68	0.32	0.44	1.85
February	2.08	0.88	0.38	0	0	2.15	0	0	0.09	0	0	2.68	0	0	3.90		1.65		0.89	1.17	2.14	2.28
Mar.	0.96	1.27	1.94	0	0	1.21	0	0	2.83	0	0	4.87	0	0	3.08		1.25		2.07	1.38	2.34	2.13
Apr 1 to Apr 15	1.25	1.73	0.48	0	0	1.17	0	0	0.69	0	0	2.19	0	0	2.47		2.10		1.28	1.72	2.54	2.44
Apr 16 to Apr 29	5.01	3.65	1.81	0	0	0.71	0	0	0.06	0	0	1.98	0	0	2.11		2.63		4.02	2.60	2.14	5.18
Apr 30 to May 13	7.93	3.67	0.85	0	0	1.45	0	0	2.20	0	0	2.68	0	0	2.43		1.57		1.56	1.27	1.60	2.44
May 14 to May 27	2.01	0.72	1.81	0	0	0.36	0	0	0	0	0	0.20	0	0	1.19		5.14		1.43	3.69	0.19	5.40
May 28 to June 10	1.07	2.38	2.92	0	0	2.85	0.6	0	2.22	0	0	1.90	0	0	3.31		2.96		3.40	3.83	0.73	2.98
June 11 to June 24	3.59	0.06	0.91	0	0	0.70	1.1	0.23	1.64	0	0	0.60	0	0	1.94		2.88		3.23	1.19	2.21	1.42
June 25 to July 8	0.27	1.63	1.42	0	0	0.12	2.4	0.17	0.97	3	0.12	0.83	1.20	0.97	6.35		1.19	1.33	2.64	3.08	0	0.63
July 9 to July 22	0.79	2.00	0.59	0.6	0.25	0.12	2.3	0.15	1.23	1	0.01	0.60	0.60	1.26	1.32	0.51	1.93	0.83	1.02	1.17	0	0.87
July 23 to Aug 5	1.17	1.76	2.88	3.9	0.06	1.80	3.3	0.65	0.56	2.27	0.25	0.72	2.47	0.69	7.23		1.26	0.99	1.37	0.58	0.73	0.71
Aug 6 to Aug 19	1.16	0.13	0.48	1.1	0.01	0.83	2.2	0.18	3.85	0	0.66	1.72	1.77	0.61	0.87	2.94	4.30	0.49	0.43	1.24	0.39	0
Aug 20 to Sep. 2	2.11	5.04	7.56	0	0.01	0.00	0	0.03	1.42	1.30	0.16	2.05	0.84	1.20	3.13	0.80	0.38		2.02	1.01	5.29	0
Sep. 3 to Sep. 16	0.11	3.04	0.42	0	0.01	1.03	0	0	0.38	0	0	0	0.86	0.23	8.77		0.04		3.03	0.28	0.19	0.28
Sep. 17 to Sep. 30	0.81	3.08	0.23	0	0	0.47	0	0	0.28	0	0	0	0	0	0.5		3.34		4.78	0.32	0.68	2.28
Total irrigation				5.6	0.33		11.9	1.41		7.57	1.20		7.74	4.96		4.25		3.64				

[a]Abbreviations: OhIrr., Overhead Irrigation; Precip. Precipitation; and SubIrr., Subirrigation.
[b]Subirrigation water use was reported for the 20 ft drainage/subirrigated drain tile spacing for corn.

Table 3. Corn grain yield for the non-drained, drainage only, and drainage/subirrigation water-table management treatments at 20 and 40 ft lateral spacings from 2002 to 2012.[a]

			Non-drained	Non-drained	Non-drained	Drainage only		Drainage/subirrigation		
Year	N source	N rate		DP	OHI	20 ft	40 ft	20 ft	40 ft	LSD (*P* = 0.05)
		lbs/acre		bu/a						
2002	AN[b]	200	63	62	—[c]	81	79	120[d]	104[d]	12
2003	AA	250	99	109	—	131	136	—	—	20
2004	Non-treated	0	97	—	83	129	115	115	63	26
	Urea	125	168	—	197	208	207	198	194	27
		250	182	—	197	215	197	216	200	13
	ESN[e]	125	181	—	197	211	214	217	205	19
		250	201	—	189	221	209	218	212	19
2005	Non-treated	0	39	—	98	66	74	72	59	23
	Urea	125	38	—	240	74	66	113	115	25
		250	28	—	263	77	61	147	126	32
	ESN	125	40	—	236	66	71	125	117	30
		250	31	—	263	52	59	139	132	26
2006	Non-treated	0	85	—	114	93	88	102	91	25
	AA	150	138	—	240	136	137	179	168	37
	ESN	150	131	—	241	139	143	203	182	40
	Urea	150	129	—	237	142	135	198	184	39
	UAN	150	123	—	227	142	137	175	171	35
2007	Non-treated	0	69	73	107	110	105	112	93	25
	AA	150	112	113	216	144	151	164	163	21
	ESN	150	116	220	220	136	152	172	167	28
	Urea	150	107	104	201	143	141	168	160	20
	UAN	150	102	98	176	136	143	152	144	18
2008[f]	AA	180	166	166	174	187	191	172	186	19
2009[f]	AA	180	71	229	44	142	135	153	99	36
2010[f]	AA	180	169	169	169	193	176	181	168	19
2011	AA	180	93	72	—	133	113	132	101	17
2012	AA+N-s	190	36	28	—	42	43	93	69	10
2013	AA+N-s	190	127	125	—	139	138	183	155	14
Average[g]			109			133	131	161	143	

[a]Comparisons within rows are valid.
[b]Abbreviations: AA, anhydrous ammonia; AN, ammonium nitrate; DP, delayed planting; N-s, N-serve (nitrapyrin); OHI, overhead irrigation, and UAN, 32% urea ammonium nitrate.
[c]Treatments were not included.
[d]The water supply provided approximately 1500 gallon/replication/day. This did not provide enough volume to substantially raise the water table; however, baseline data was established on the impact of subirrigation on corn production in 2002.
[e]Polymer coated urea (Agrium, Calgary, Alberta, Canada).
[f]Grain yield was averaged over hybrid (Kruger 2114 RR/YGCB, LG 2642BtRR, Asgrow 785 VT3, DKC 61-73, and DKC 63-42.
[g]Calculated as the average yield for 2002, ESN at 250 lb/a in 2004 and 2005, ESN at 150 lb/a in 2006 and 2007, and anhydrous ammonia in 2008, 2009, 2010, 2011, and 2012.

Table 4. Soybean grain yield for non-drained, drainage only, and drainage/subirrigation water-table management treatments at 20 and 40 ft lateral spacings from 2002 to 2013.

Water-table management	2002	2003	2004	2005	2006	2007[a]	2008[b]	2009[c]	2010[c]	2011	2012	2013	Average[d]
					bu/acre								
Non-drained	36	40	57	38	63	41	37	48	59	42	29	35	44
Non-drained delayed planting[e]	36	42	45	38	61	40	35	44	64	43	28	33	43
Drainage only													
20 ft lateral spacing	45	48	71	45	66	50	45	50	65	56	37	39	52
40 ft lateral spacing	46	48	72	41	66	48	46	49	69	51	34	38	51
Drainage/subirrigation													
20 ft lateral spacing	——[f]	46	72	54	65	61	39	50	62	64	65	54	57
40 ft lateral spacing	——	47	69	51	66	60	40	49	65	59	50	49	55
LSD (P = 0.05)	— 3 —	— 3 —	— 3 —	— 5 —	— 3 —	— 6 —	— 7 —	— 4 —	— 5 —	— 4 —	— 4 —	— 5 —	

[a]Soybean cultivar was Kruger 382.
[b]Soybean yield was averaged over Kruger 382, Pioneer 93M96, NK S37-N4, Asgrow 3602, and Morsoy 3636N.
[c]Averaged over Headline at R3, Headline at R5, Headline at R3 and R5, and Headline plus Warrior at R3 and R5, and a non-treated control. Grain yields were ranked Headline plus Warrior at R3 and R5 = Headline at R5 > Headline at R3 and R5 = Headline at R3 = non-treated control for the fungicide treatment main effects in 2009. Grain yields were ranked Headline plus Warrior at R3 and R5 = Headline at R3 and R5 = Headline at R3 ≥ Headline at R5 > non-treated control for the fungicide treatment main effects in 2010.
[d]Calculated as the average yield for 2003-2012.
[e]The planting date was delayed 3, 2, 14, 0, 4, 0, 0, 0, 0, 0, 0, and 0 days after the drainage only and drainage/subirrigation treatments in 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, and 2013 respectively.
[f]Treatments were not included.

SOYBEAN YIELD RESPONSE TO DRAINAGE AND SUBIRRIGATION OF A CLAYPAN SOIL IN NORTHEAST MISSOURI

Kelly Nelson
Research Agronomist

Randall Smoot
Superintendent

Clinton Meinhardt
Research Specialist

Although agricultural drainage is a familiar system, using drainage as part of an integrated water management system (IWMS) is a relatively new concept that improves water quality and sustains agricultural viability (Fausey et al., 1995; Fisher et al., 1999; Allred et al., 2003; Drury et al., 1996, 2009). Subsurface drainage water from agricultural lands with properly installed IWMS can contribute to the quantity and quality of water in receiving streams. An IWMS uses subsurface drainage to remove excess water in the spring and fall for critical field operations, regulate water flow (managed drainage), and add water to the field through subirrigation (Belcher and D'Itri, 1995; Skaggs, 1999; Frankenberger et al., 2006). Drainage plus subirrigation provides water to the crop through the use of water level control structures, usually requires narrower drain spacings, and can be an efficient method of delivering water to the crop (Belcher and D'Itri, 1995; Brown et al., 1997; Skaggs, 1999). In a high-yield soybean production system, DSI with tile lines on 20 ft spacings increase soybean yields 24 bu/acre compared to a nonirrigated control on soils with a fragipan 14 to 30 inches deep in Ohio (Cooper et al., 1992). In narrow rows (7 inches), long-term soybean yields using DSI reached 80 bu/acre in the 1980s (Cooper et al., 1991). From November to May, upland, flat claypan soils commonly have a seasonal perched water table caused by an impermeable underlying argillic clay layer that restricts internal drainage. During summer, these soils quickly dry out and drought can devastate crop production. Previous research has evaluated the effects of drainage systems on response of corn (Walker et al., 1982; Sipp et al., 1986; Nelson et al., 2009), soybean (Walker et al., 1982; Sipp et al., 1984), and alfalfa (Rausch et al., 1990), but no studies to date have evaluated DSI as part of an IWMS on soybean response in a claypan soil. Simulation research for a Cisne silt loam (claypan soil in southern Illinois) called for a 20 ft drain tile spacing for DSI with good surface drainage, and 16 ft spacing when with poor surface drainage (Mostaghimi et al., 1985). However, research has neither verified these recommendations in the field, nor evaluated the effect of drain tile spacing on soybean response.

Since shallow drain tile depths and narrow spacings are recommended for claypan soils, field research from 2003–2006 was conducted to evaluate the effects of drainage (DO) and DSI on planting date and the effects of DO and DSI at 20 and 40 ft spacings on soybean yield compared to non-drained (ND) and non-drained delayed planting (NDDP) controls on claypan soils. Soybean were planted up to 17 d earlier with DO or DSI systems. Plant populations were reduced 29 to 52% in the non-drained control due to poor drainage in 3 of the 4 yr (data not presented). Grain yield (Table 1), water applied through the DSI system, and water level depth were similar at a 20 or 40 ft drain tile spacings (data not presented). Average yield increase with DSI at 20 and 40 ft spacings was 12 to 29% (6–14 bu/acre) while DO at the same spacings increased yield 9 to 22% (4–11 bu/acre) compared to ND or NDDP controls (Table 1). In a dry year (2005), drainage plus subirrigation increased yield up to 18 bu/acre compared to DO. Plant population variability at harvest was lower with the DO or DSI systems compared to ND or NDDP controls (data not presented). Yield variability over the 4 yr was lower with DSI compared with DO or ND controls (Table 1), which was affected by the spring–summer precipitation regimes and is important to farmers for a more predictable soybean marketing strategy.

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Table 1. Grain yield for drain tile spacings and drainage water management systems from 2003 to 2006. The spring-summer precipitation regimes are in parentheses.

	2003 (wet-mod.)		2004 (wet-wet)		2005 (dry-dry)		2006	Average yield	
Drain tile spacing (ft)	DO[†]	DSI	DO	DSI	DO	DSI	(mod.-mod.)	DO	DSI
Yield	bu/acre								
Non-drained	40.3	42.2	56.8	45.3	38.0	38.3	62.1	52.3 ± 12.6[§]	47.0 ± 10.6[‡]
20 ft spacing	48.5	46.5	70.9	71.9	45.8	58.4	64.8	57.5 ± 12.3	60.5 ± 10.8
40 ft spacing	48.2	47.3	72.1	68.7	40.6	51.1	66.3	56.8 ± 14.9	58.4 ± 10.7
LSD (P = 0.05)	3.9		9.2		7.9		2.1		

[†] Abbreviations: Drainage only, DO; DSI, Drainage plus subirrigated; LSD, Least Significant Difference; mod., moderate; NS, Non-Significant.
[‡] Non-drained delayed-planting control.
[§] Standard deviation.

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YIELD RESPONSE OF SOYBEAN CULTIVARS TO SUBSURFACE DRAINAGE AND SUBIRRIGATION IN NORTHEAST MISSOURI

Kelly Nelson
Research Agronomist
Randall Smoot
Superintendent
Clinton Meinhardt
Research Specialist

Excessive springtime precipitation can be followed by periods of low rainfall during summer that can lower soybean grain yields. Combining water management and subirrigation during summer months could help farmers reduce year-to-year production variability of soybean on claypan soils. Drainage plus subirrigation (DSI) uses subsurface drainage to remove excess water in spring and fall for critical field operations, regulate water flow during winter (controlled drainage), and add water to the field. Claypan soil research has evaluated the effects of drainage systems on corn (Nelson et al., 2009; Sipp et al., 1984; Walker et al., 1982), soybean (Sipp et al., 1984; Walker et al., 1982), and alfalfa (Rausch et al., 1990) response, but not the effects of DSI as part of an integrated water management system on high yielding soybean cultivar response in a claypan soil. Limited DSI research has evaluated its effects on response for different soybean cultivars (Cooper et al., 1992) and grain quality (Wiersma et al., 2010). Hence, a need existed to evaluate soybean cultivar responses to different drain tile spacings. The objective of this research was to evaluate the effects of cultivar selection and drainage water management system at 20 and 40 ft spacings on soybean response in a claypan soil.

Field research in 2007 and 2008 evaluated effect of cultivar (Kruger 382, Morsoy 3636, Asgrow 3602, Pioneer 93M96 and NKS37-N4) and DO or DSI at 20 and 40 ft drain tile spacings on soybean response. Yields were similar for DO and DSI at 20 and 40 ft spacings when yield potential for cultivars in the non-drained control was 37 to 40 bu/acre (Table 1). Kruger 382 yield increased 7 bu/acre with DSI on a 20 ft spacing compared to DO, but yields were similar between DO and DSI systems for other cultivars. Using DSI and DO, Kruger 382, Morsoy 3636, and Asgrow 3602 increased yields 15 to 46% (7 to 17 bu/acre) compared to the non-drained control. However, Pioneer 93M96 or NKS37-N4 yields were not affected by DO or DSI. Oil concentration of Morsoy 3636 and Asgrow 3602 decreased up to 0.3% with DO at a 20 ft spacing, but drainage had no effect on oil concentration of Kruger 382, Pioneer 93M96, or NKS37-N4 (data not presented). It was important to match high yielding cultivars with appropriate drainage water management systems.

Table 1. The interaction of cultivar and water management systems on yield. Water management systems were drainage only (DO) and drainage plus subirrigation (DSI). Data were combined over years (2007 and 2008) in the absence of a significant interaction.

	Yield				
		DO	DO	DSI	DSI
Cultivar	Non-drained	20 ft	40 ft	20 ft	40 ft
	Bu/acre				
Kruger 382	37	47	47	54	53
Morsoy 3636	40	49	47	51	49
Asgrow 3602	37	47	46	51	46
Pioneer 93M96	38	46	46	42	44
NKS37-N4	40	45	45	44	43
LSD (*P* = 0.05)	7				

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DRAINAGE WATER MANAGEMENT AND HEADLINE FUNGICIDE EFFECTS ON SOYBEAN YIELD

Kelly A. Nelson
Research Agronomist

Clinton Meinhardt
Research Specialist

Production challenges associated with cool, wet soils in the spring, drought during the summer, and wet conditions in the fall have caused farmers to consider new production systems that maximize yield and maintain environmental sustainability. Subsurface tile drainage on 20 ft spacings increased soybean yields 4 bu/acre compared to a non-drained control on a claypan soil in southern Illinois (Walker et al., 1982). However, no research has evaluated how drainage water management (DWM) affects the severity of foliage diseases in soybean. Drainage plus subirrigation (DSI), as a DWM practice, could reduce leaf wetness associated with overhead irrigation and provide a climate that is less favorable to foliage diseases. In a high-yield soybean production system, DSI with tile lines 20 ft apart increased soybean yields 24 bu/acre compared to a nonirrigated control on soils with a fragipan 14 to 30 inches deep in Ohio (Cooper et al., 1992). In narrow rows (7 inches), long-term soybean yields using DSI reached 80 bu/acre in the 1980s (Cooper et al., 1991), with the use of benomyl every 2 wk and permethrin as needed. Control of foliage diseases was recommended as a part of high-yield (>75 bu/acre) management system that used overhead irrigation or had high rainfall (Cooper, 1989). Frogeye leaf spot (FLS) (*Cercospora sojina*) was managed with benomyl (Dashiell and Akem, 1991; Akem, 1995), and a split application (R1+R3) was more effective in managing the disease than early vegetative applications (Akem, 1995). More recently, research evaluating strobilurin fungicides applied from R3 to R5 increased yield up to 6 bu/acre in the presence of Septoria brown spot (SBS) (*Septoria glycines*) and/or FLS (Cruz et al., 2010; Dorrance et al., 2010; Nelson et al., 2010). However, there was no soybean yield increase with pyraclostrobin applied during the vegetative stage of development (Nelson et al., 2010; Bradley and Sweets 2008). High-yield production systems have started combining preventive fungicide and insecticide treatments to manage soybean aphids (*Aphis glycines* Matsumura) along with SBS or FLS (Dorrance et al., 2010; Nelson et al., 2010). Such treatments increased yield 9 bu/acre averaged over eight of the nine locations depending on insect threshold levels and severity of disease (Dorrance et al., 2010).

Headline fungicide has been used to protect soybean [*Glycine max* (L.) Merr] from foliar diseases, while its interaction with drainage water management (DWM) systems was unknown. Field research was conducted during two wet years (2009 and 2010) with 3.8 inches of rainfall greater than the past decade average. The objective of this research was to evaluate the effects of Headline (6 oz/acre) application timing (R3, R5, R3+R5, and R3+R5+Warrior insecticide at 2.6 oz/acre) and DWM system (nondrained and drainage only [DO] or drainage plus subirrigation [DSI] at 20 and 40 ft drain tile spacings) on soybean yield, grain quality, and severity of SBS and FLS. Grain yields increased 18 to 22% with DO or DSI at 6.1 and 12.2 m spacings compared to a nonfungicide treated, nondrained control (Table 1). In the absence of drainage, pyraclostrobin with or without lambda-cyhalothrin increased yields 20 to 27% compared to the nondrained, nonfungicide treated control. The combination of DWM and pyraclostrobin increased grain yields up to 36%. Pyraclostrobin plus lambda-cyhalothrin at R3+R5 increased yield 8 to 12% except with DO at 40 ft compared to similar nonfungicide-treated DWM systems. A DWM and pyraclostrobin interaction was detected for grain oil and protein concentration, but differences were minimal (data not mentioned). Pyraclostrobin with or without lambda-cyhalothrin reduced severity of SBS and FLS 2 to 8% depending on the year (data not presented), but DWM did not affect severity of these diseases. The greatest synergistic yield increase on a claypan soil occurred when foliar disease management and DWM systems were used together in years with higher than normal rainfall.

Table 1. Soybean yield response from Headline (6 oz/acre) application timings and drainage water management systems at 20 and 40 ft spacings. Data were combined over 2009 and 2010.

Headline application timing†	Non-drained	DO 20 ft	DO 40 ft	DSI 20 ft	DSI 40 ft
	------------------------ bu/acre ------------------------				
Non-treated	45	53	55	53	55
R3‡	54	59	59	57	58
R5	54	56	59	56	55
R3+R5	56	57	59	55	56
R3+R5+Warrior insecticide§	57	60	60	58	61
LSD (P = 0.05)	-------------------------- 5 --------------------------				

†Abbreviations: DO, drainage only; DSI, drainage plus subirrigation.
‡Growth stages at which pyraclostrobin were applied (Fehr and Caviness, 1971).
§Lambda-cyhalothrin at 2.6 oz/acre.

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USE OF SLOW-RELEASE N FERTILIZER TO CONTROL NITROGEN LOSSES DUE TO SPATIAL AND CLIMATIC DIFFERENCES IN SOIL MOISTURE CONDITIONS AND DRAINAGE

Sara Merchán Paniagua
Graduate Student

Kelly Nelson
Research Agronomist

Peter Motavalli
Associate Professor

Steve Anderson
Professor

John Sadler
USDA - ARS

Losses of nitrogen (N) from N fertilizer applications to corn may reduce N use efficiency and thereby decrease corn yields and have possible negative effects on the environment. Among the major N loss processes are leaching and production of N gases, such as nitrous oxide (N_2O). The relative significance of these processes in claypan soils may vary due to annual differences in rainfall and temperature and the presence of a restrictive subsoil layer that reduces drainage. Production of N_2O gas after N fertilization may be relatively higher in claypan soils because more of this N gas is produced under wet soil conditions. Application of enhanced efficiency N fertilizers, such as slow release N fertilizer, may reduce N losses that would occur if conventional urea fertilizer was applied because its N release may be delayed during the early growing season when the risk of leaching and gaseous N losses is high.

The objective of this research was to examine the performance and cost-effectiveness of polymer-coated urea and conventional N fertilizers, and the relationship between soil N_2O flux, temperature, soil nitrate-N (NO_3^--N), and soil water content. A two-year field trial planted to corn was started in 2004 at the University of Missouri Ross Jones Farm in Northeast Missouri on a claypan soil. Treatments consisted of 150 ft long plots with: i) no drainage or subirrigation, ii) drainage with tile drains spaced 20 ft apart and no subirrigation, iii) drainage with tile drains spaced 20 ft apart and subirrigation, and iv) no drainage and overhead irrigation. The plots were then split into N fertilizer treatments of broadcast pre-plant-applied urea or polymer-coated-urea at rates of 0, 125, and 250 lbs N/acre. Each treatment combination had 4 replications.

Changes in soil volumetric water content and temperature due the effects of drainage and irrigation over the growing season were continuously monitored in two replicates of the field experiment using Campbell Scientific data loggers and soil moisture and temperature sensors. The sensors were installed at depths of 6 and 18 inches in the middle between drainage tile lines and in the control and high rate of urea fertilizer.

Soil sampling was periodic (every week from late April to late June and every other week until late September) to monitor the fate of applied fertilizer by changes in soil ammonium-N (NH_4^+-N) and NO_3^--N by depth, by NO_3^--N analysis of water samples collected from suction lysimeters installed at depths of 6 and 18 inches, and by measurement of nitrous oxide gas flux. Soil N_2O gas was collected using small sealed chambers fitted with rubber septa inserted into PVC collars in the soil. The head space gas was collected from the chambers in the different treatments and analyzed by gas chromatography. Crop N recovery of applied fertilizer N due to the treatments was determined by measurement of total aboveground biomass at two different times during the season and at physiological maturity and by total N tissue analysis.

The results show that in the 2004 growing season when cumulative rainfall was 21 in., grain yields averaged approximately 94 bu/acre higher than the check plots receiving no N fertilizer across all drainage and irrigation treatments (Figure 1A). In addition, the plots in 2004 with drainage generally out yielded the non-drained plots by 23 to 31 bu/acre. Yield increases due to use of polymer-coated urea compared to conventional urea N fertilizer ranged from an average of 14 to 20 bu/acre in the plots with no drainage or supplemental irrigation, but these yield increases were not significant (Figure 1A). In 2005, some yield advantage was observed with drainage, but, in general the largest response occurred when irrigation was applied (Figure 1B). The importance of irrigation in 2005 was due to lower rainfall (10.4 in.) experienced during the growing season. No significant yield differences were observed between polymer-coated and conventional urea (Figure 1B).

In 2004, drainage significantly reduced gravimetric soil water content compared to non-drained plots only at the beginning of the growing season (Fig 3A). Overhead irrigation increased soil water content at the end of the 2004 season and after 67 days after N application in the 2005 season (Fig 3A&B). Only 5.6 in. of irrigation was applied near the end of the 2004 season because it was a relatively wet year (Fig 3A). In contrast, overhead irrigation had a large impact on gravimetric soil water content in 2005 (11.9 in. was applied for the growing season).

Nitrate-N levels contained in suction lysimeter water samples at depths of 6 and 18 inches in 2004 were highly variable and collection of samples only began 60 days after the N fertilizer was applied (DAN) since insufficient water was in the soil to enter the suction lysimeters until that date. Despite the high variability in NO_3^--N contained in the water samples, the NO_3^--N was generally higher in the urea-treated plots compared to the polymer-coated urea in the beginning of the season (60, 68 and 85 DAN) and then lower later in the season (139 and 158 DAN). In 2005, sufficient water was found only two sampling dates (55 and 67 DAN). Higher nitrate-N levels were found in the urea-treated plots 67 days after application of N sources.

Soil N_2O flux was significantly lower in 2004 in the polymer coated urea-treated plots at the beginning of the season in the overhead irrigated, non-drained plots (Figure 2A). Only plots with overhead irrigation and no drainage were graphed as they were assumed to have had better conditions for release of N_2O than the other drainage/irrigation treatments. In 2005, the only significant difference between fertilizers was observed at 41 days after N application when urea-treated plots released less N_2O than plots receiving polymer coated urea and after 125 days when both urea and polymer coated urea-treated plots had higher N_2O flux than the control (Figure 2B). In general, polymer-coated urea had lower surface soil N_2O efflux compared to urea in the early part of the growing season during a relatively wet year. These results suggest polymer-coated urea may reduce N_2O losses under relatively wet conditions.

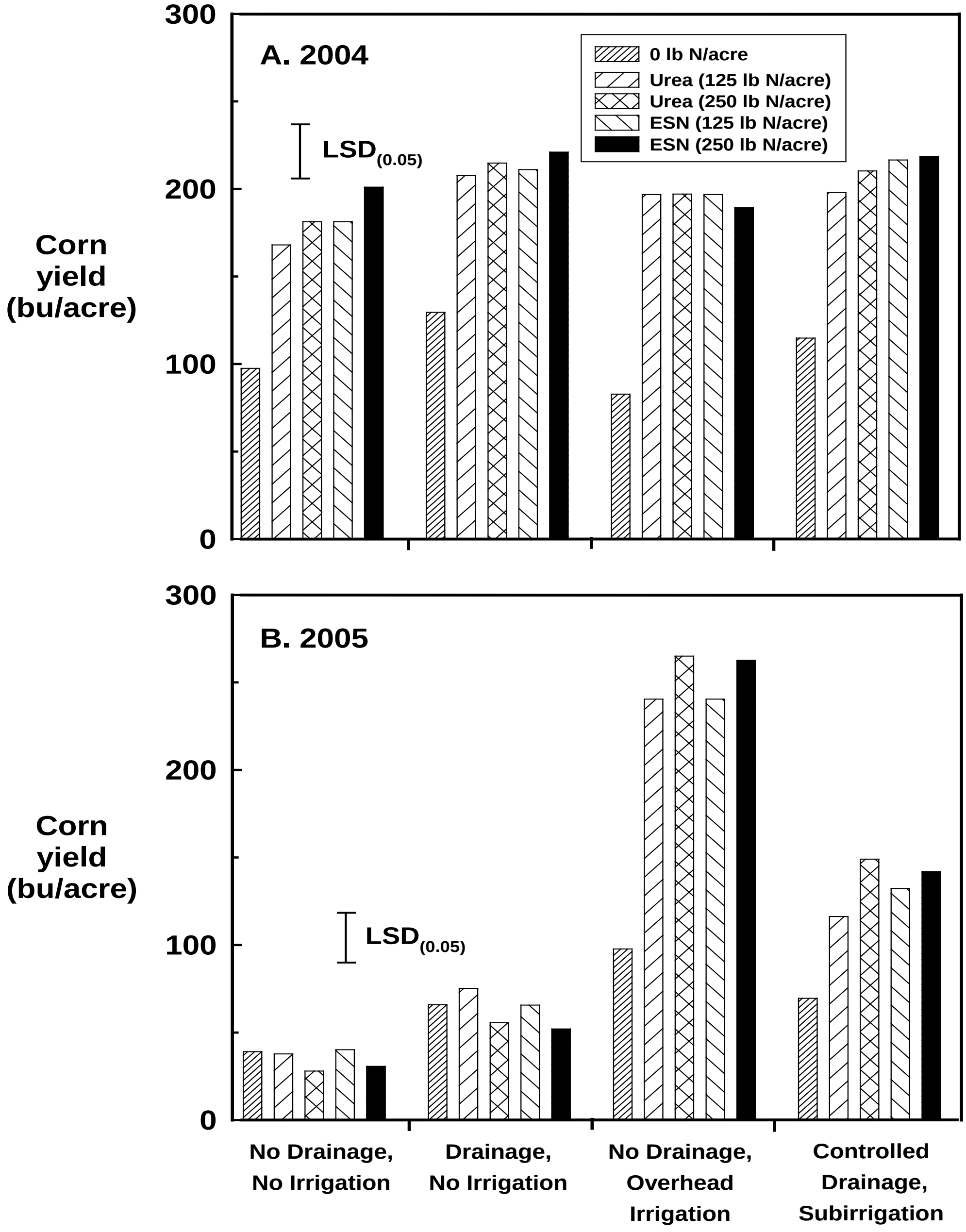

Figure 1A & B. Corn grain yield response in A) 2004 and B) 2005 to different application rates of conventional and polymer-coated urea (ESN) under different drainage and irrigation treatments. All sampling times without LSD bars were not significant. LSD $_{(0.05)}$ = Least significant difference at 0.05 significance level.

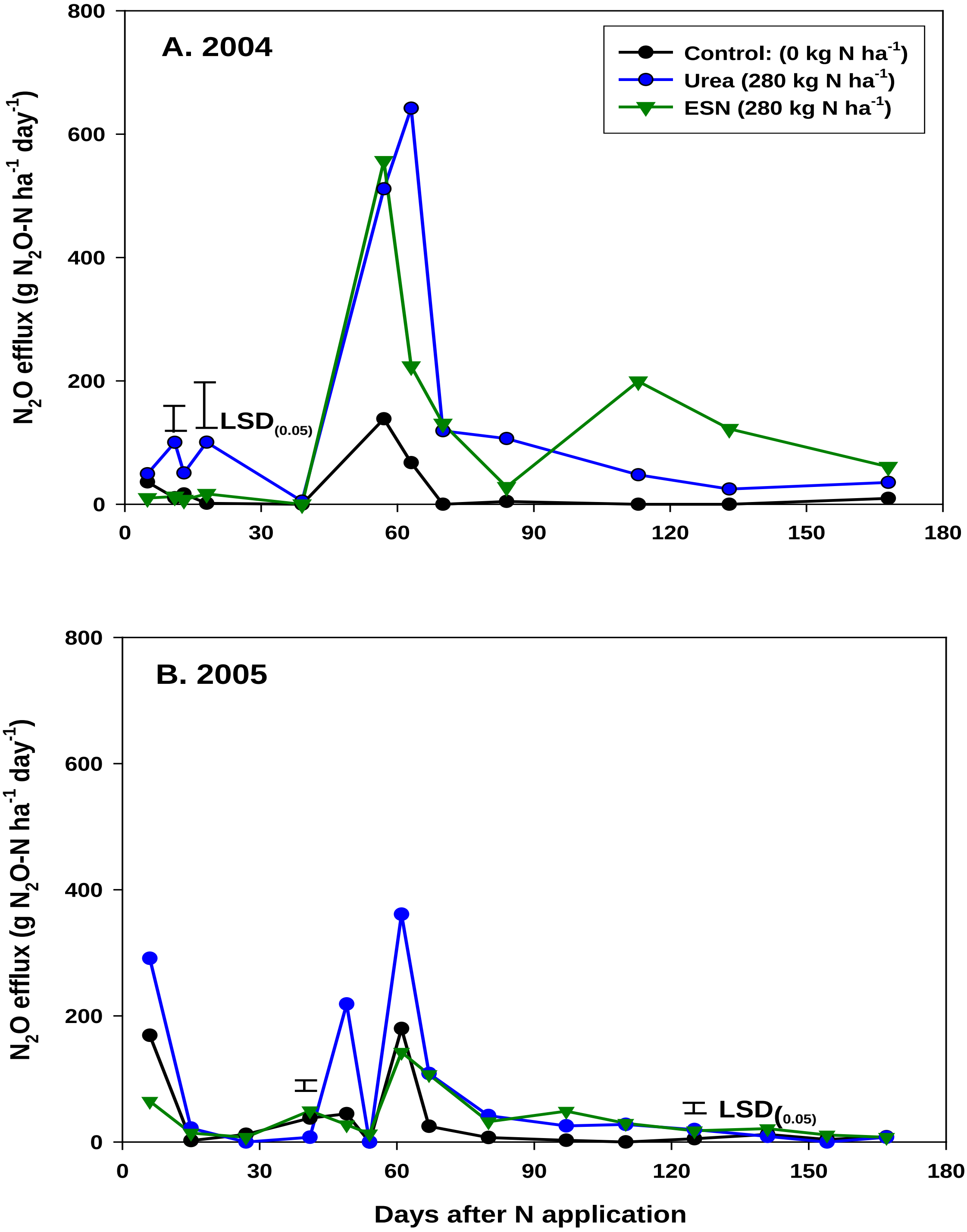

Figure 2A & B. N_2O efflux under each fertilizer treatment in the overhead irrigated, non-drained plots over the growing season in (A) 2004 and (B) 2005. Sampling times without LSD bars were not significant. LSD $_{(0.05)}$ = Least significant difference at 0.05 significance level.

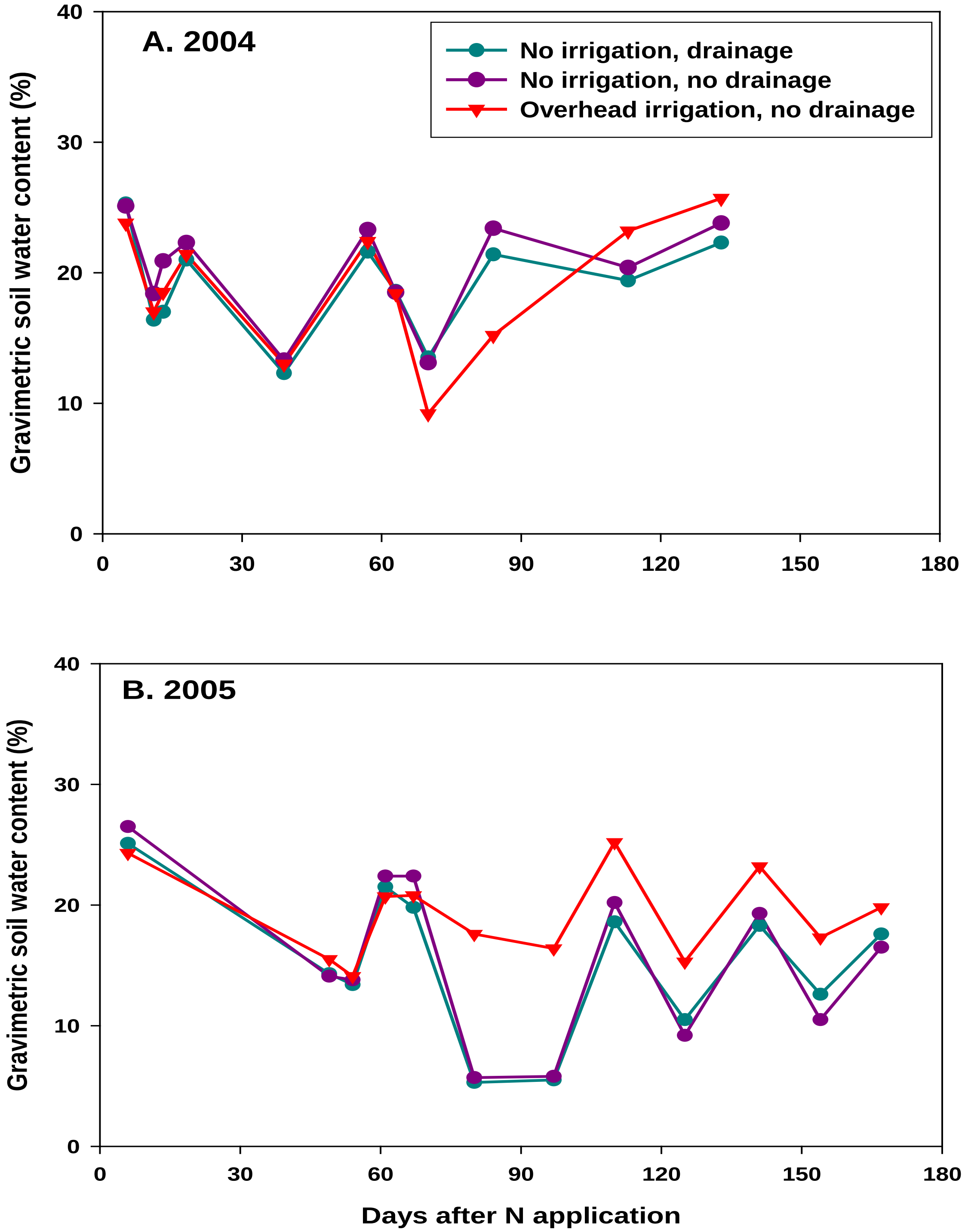

Figure 3A & B. Gravimetric soil water content (A&B) at 5 cm depth under each drainage and irrigation treatment after application of 280 kg N ha^{-1} (as ESN) over the 2004 and 2005 growing seasons. All sampling times without LSD bars were not significant. $LSD_{(0.05)}$ = Least significant difference at 0.05 significance level.

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NITROGEN SOURCE AND DRAIN TILE SPACING AFFECTS CORN YEILD RESPONSE IN A CLAYPAN SOIL

Kelly A. Nelson
Research Agronomist

Peter Motavalli
Professor

Research in corn has evaluated interactions between drainage and nitrogen management (Drury and Tan, 1995; Kladivko et al., 1999) as well as water quality (Fausey et al., 1995; Drury et al., 1996; Kladivko et al., 2004; Randall and Goss, 2001). Computer simulations of southern Illinois soils indicated the need for 20 ft drain tile lateral spacing for drainage and subirrigation (Mostaghimi et al., 1985). Limited research has evaluated how drainage affects corn response (Sipp et al. 1986; Rausch et al., 1990; Nelson et al., 2009). No research has evaluated the effects of drainage or drainage plus subirrigation drain tile spacings in a claypan soil. Enhanced efficiency N application rates have been evaluated in claypan soils (Nelson et al., 2009; Noellsch et al., 2009; Nash et al., 2012), but no studies have looked at the impact of N source selection and the interaction with different drain tile spacings and water management systems in a claypan soil. The objective of this research was to evaluate corn yield, plant population, grain protein, and grain N removal response to subsurface tile drainage or drainage plus subirrigation tile spacings and N sources.

Research in 2006 and 2007 evaluated the effects of nitrogen (N) sources [non-treated control, anhydrous ammonia, urea, polymer-coated urea (PCU), and 32% urea ammonium nitrate (UAN) at 150 lbs N/acre] and water management systems [drained, non-irrigated (DNI) at 20, 30, and 40 ft spacings; non-drained, non-irrigated (NDNI); non-drained, overhead irrigated (NDOHI); and drained plus subirrigated (DSI) at 20, 30, and 40 ft spacings] on corn (Zea mays L.) yield, plant population, grain protein, and grain N removal. DNI increased grain yield 15 to 30 bu/acre (10% to 22%) compared to NDNI (Table 1). DSI increased yields up to 70 bu/acre (24% to 38%) depending on N source and spacing. DSI increased yields 10% to 28% compared to DNI. Nitrogen sources in the NDOHI increased yields 42% to 45% compared to NDNI, and 10% to 20% compared to DSI at a 20 ft spacing. In irrigated and poorly drained claypan soil (NDOHI), PCU increased yield 14 bu/acre compared to NCU. PCU had the highest yields among N sources with DSI at 20 ft, DSI at 30 ft, DSI at 40 ft, and DNI at 40 ft. In a well drained soil (DNI at 20 ft), NCU had the highest yield (142 bu/acre) among N sources, while anhydrous ammonia had the highest yields in the NDNI control (125 bu/acre) and DNI at 30 ft (144 bu/acre). Grain N removal was greatest (226 to 227 lbs/acre) with anhydrous ammonia and PCU with NDOHI (data not presented). Nitrogen source selection is an important component of high-yielding corn production systems depending on water management system.

Table 1. Effects of water management and N source applied at 150 lbs N/acre on corn grain yield. Date were combined over years 2006 and 2007.

Water management system	NTC[†]	AA	NCU	PCU	UAN
	------------------- bu/acre -------------------				
Non-drained, non-irrigated (NDNI)	79	125	117	120	110
Drained, non-irrigated at 20 ft (DNI 20)	101	140	142	138	139
Drained, non-irrigated at 30 ft (DNI 30)	93	144	144	139	136
Drained, non-irrigated at 40 ft (DNI 40)	96	144	138	148	140
Drained plus subirrigated at 20 ft (DSI 20)	106	173	187	190	166
Drained plus subirrigated at 30 ft (DSI 30)	92	169	170	171	151
Drained plus subirrigated at 40 ft (DSI 40)	92	165	172	174	157
Non-drained, overhead irrigated (NDOHI)	110	216	207	221	197
LSD (P = 0.05)	------------------------ 13 ------------------------				

[†]Abbreviations: AA, anhydrous ammonia; NCU, non-coated urea; NTC, non-treated control; PCU, polymer-coated urea; and UAN, 32% urea ammonium nitrate.

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CORN HYBRID RESPONSE TO DRAINAGE, DRIANAGE PLUS SUBIRRIGATION, AND NON-DRAINED OVERHEAD IRRIGATION

Kelly A. Nelson
Research Agronomist

Randall Smoot
Superintendent

Within-season climate variability is a primary factor affecting corn yields in Missouri. Although Midwestern farmers have been planting up to two weeks earlier than in the 1980's, recommendations for initiating planting continue to be based on field conditions and soil temperature. Soils that are cool and wet can delay planting. Adequate soil drainage helps soils dry and warm quickly. The distribution of rainfall in upstate Missouri generally peaks in mid-April to mid-May, with periods of drought and little water available to plants in late June, July, and early August. Drought conditions during July and August are usually yield-limiting in claypan soils, due to their low water-holding capacity. However, these soils' poor drainage may contribute to excessive yield loss, due to stand loss, fertilizer loss, and poor root development.

A study evaluated corn (*Zea mays* L.) hybrids (Asgrow 785, DKC 61-73, DKC 63-42, LG 2642, and Kruger 2114) and water management systems (nondrained, nonirrigated (NDNI); drained, nonirrigated (DNI) with subsurface drain tiles 20 and 40 ft apart; drained plus subirrigated (DSI) with tiles 20 and 40 ft apart; nondrained, overhead irrigated (NDOHI)) on yields, plant population, and grain quality from 2008 to 2010. Precipitation during this study was 1.4 to 11 inches above the past decade average. Planting date was delayed 18 d in the nondrained control in 2009, and additional delayed planting controls were included this year (Table 1). Grain yields were similar in the 20- and 40 ft-spaced DNI and DSI systems in 2008 and 2010 (Table 2), but plant population increased 74% (data not presented) and yields were 49 bu/acre greater with DSI at a 20 ft spacing compared to 40 ft spacing in 2009 (Table 1). At a 20 ft spacing, DNI or DSI increased yield 17 to 105 bu/acre (10 to over 50%) compared to NDNI or NDOHI soil (Table 2). High yielding hybrids achieved similar yields with DNI, while NDNI DKC63-42 had 19 bu/acre greater yields compared to DKC61-73. A 20 ft spacing for DNI claypan soils is recommended for high yielding corn production in high rainfall years. Additional information on this research is available in Nelson, K.A., and R.L. Smoot. 2012. Corn hybrid response to water management practices on claypan soil. Int. J. Agron. doi:10.1155/2012/925408.

Table 1. Water management main effects for grain yield in 2009. Data were combined over hybrids.

Water management system	Yield
	bu/acre
Non-drained, non-irrigated (NDNI)	72
Non-drained, non-irrigated, delayed planting (NDNIDP)	229
Drained, non-irrigated (DNI) at 20 ft	146
Drained, non-irrigated (DNI) at 40 ft	121
Drained plus subirrigated (DSI) at 20 ft	156
Drained plus subirrigated (DSI) at 40 ft	107
Overhead irrigated, non-drained (NDOHI)	41
Overhead irrigated, non-drained, delayed planting (NDOHIDP)	204
LSD (*P* = 0.05)	48

Table 2. Corn grain yield response to water management systems and hybrid in 2008 and 2010. Data were combined over years.

Hybrid†	NDNI	DNI 20	DNI 40	DSI 20	DSI 40	NDOHI
	------------------------------ bu/acre ------------------------------					
DKC63-42	176	194	186	184	192	170
LG2642	172	186	188	176	176	181
Asgrow785	167	192	184	175	170	175
Kruger2114	164	178	178	167	176	169
DKC61-73	157	192	178	172	165	162
LSD (*P* = 0.05)	------------------------------ 17 ------------------------------					

†Abbreviations: DNI 20, drained, non-irrigated (20 ft drain spacing); DNI 40, drained, non irrigated (40 ft drain spacing); DSI 20, drained, subirrigated (20 ft drain spacing); DSI 40, drained, subirrigated (40 ft drain spacing), NDNI, non-drained, non-irrigated; and NDOHI, non-drained, overhead irrigated.